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Caveats for the COmbined Radar-Radiometer Algorithm (CORRA) Level 2 Products in the GPM/TRMM V07 Public Releases

The GPM COmbined Radar-Radiometer Algorithm (CORRA) L2 V07 product includes precipitation estimates over the full, 245 km Ku radar swath (Ku+GMI inputs, as well as Ku+Ka+GMI inputs after May 21, 2018), and estimates over the narrower, 125 km inner swath (Ku+Ka+GMI inputs before May 21, 2018). The inputs for the GPM CORRA L2 algorithm are derived from DPR L2 and GMI L1C products. In particular, the CORRA L2 algorithm draws upon inputs from the DPR L2 Preparation Module, Classification Module, Surface Reference Technique Module, and the Vertical Structure Module. From GMI L1C, the GPM L2 algorithm inputs the intercalibrated brightness temperature observations. CORRA has also been extended to produce TRMM precipitation products from a combination of precipitation radar (PR) and TRMM microwave imager (TMI) data, using essentially the same estimation method that is applied to GPM. In this case, estimates based on only the Ku+TMI inputs over the Ku radar swath are produced, since no Ka band radar data are available from TRMM.

During the early GPM mission (prior to June 2014) many tests and modifications of the DPR performance were carried out, and these had an impact on not only DPR products but also the GPM CORRA L2 estimates that depend on them. Therefore, GPM CORRA L2 precipitation estimates from the early mission should be used with caution. A listing of the orbits impacted by these tests and modifications can be obtained from the GPM Radar Team.

Mainlobe and sidelobe clutter contamination of DPR reflectivities is reduced using radar beam reshaping and statistical corrections. The combination of these applications reduces clutter successfully over most surfaces, but there are still "exceptional" regions where clutter signatures are still evident. Also, ice-covered land surfaces produce Ku-band radar surface cross-sections at nadir view that sometime exceed the upper limit of the radar receiver range. Estimates of Ku-band path-integrated attenuation from the Surface Reference Technique Module are possibly biased in these regions. Since radar reflectivities and path-integrated attenuations are utilized by the CORRA L2 algorithm, precipitation estimates in these "exceptional" regions should be used with caution.

The current GPM CORRA L2 algorithm uses the Ku-band radar reflectivities from the Preparation Module to detect either liquid- or ice-phase precipitation. The lowest detectable reflectivity for DPR at Ku band is ~13 dBZ, and so light snow or very light rainfall may not be detected and quantified by the algorithm. The TRMM PR radar has a minimum detectable signal of ~18 dBZ, and so even more light snow and rainfall may not be quantified by TRMM CORRA.

In addition to the impact of input data from DPR L2, there are uncertainties due to the current limitations of the CORRA L2 algorithm's physical models and other assumptions that can also have an impact on precipitation estimates. In particular, the physical models for scattering by ice-phase precipitation particles now feature realistic nonspherical particle geometries, but these particle models are still undergoing development. The scattering models for ice- and mixed-phase precipitation will likely be improved in future product releases. Also, the effects of radar footprint non-uniform beamfilling and multiple scattering of transmitted power are addressed in CORRA L2, but the strategies that have been implemented to handle these effects are not yet generalized and have not been analyzed in detail. Multiple scattering primarily affects Ka-band reflectivities, and it sometimes eliminates Earth surface reflection in regions of strong radar attenuation (although attenuation can sometimes eliminate the surface signal even if multiple scattering effects are small). Footprint non-uniform beamfilling impacts the interpretation of both Ku- and Ka-band radar data. As a consequence, CORRA L2 precipitation estimates associated with intense convection, in particular, will have greater uncertainties. Finally, the assumed *a priori* statistics of precipitation particle size distributions can have an influence on estimated precipitation. As particle size distribution data are collected during the mission, more appropriate assumptions regarding the *a priori* statistics of particle sizes will be specified in the algorithm. At this stage of the mission, however, relatively simple assumptions regarding particle size distributions have been introduced into the algorithm, and so biases in estimated precipitation rates and the associated particle size distributions can occur. The correct diagnosis of particle sizes in CORRA L2 estimates may require more general constraints on particle size distribution parameters, and these constraints are the subject of ongoing studies.

It should also be noted that both precipitation estimates and retrievals of environmental parameters from CORRA L2 have not yet been comprehensively validated using ground observations. Such a validation effort is under way and will continue to expand after the GPM/TRMM V07 release of products. Therefore, it is very important that users of these public release products keep in contact with the Combined Algorithm Team for updates on the validation of precipitation estimates and any reprocessing's of CORRA L2 products.

Preliminary validation of the GPM CORRA L2 V07 product has revealed good consistency between estimated precipitation rate and raingauge-calibrated radar. At footprint scale, matches of the GPM CORRA V07 with raingauge-calibrated radar (Multi-Radar Multi-Sensor [MRMS] product) over the continental US/lower Canada and coastal waters during the June – December 2018 period (post HS scan shift) yielded total low biases of 9% for the Ku+Ka+GMI product and 5% for the Ku+GMI product, with correlations to MRMS of about 0.76 for both products. Considering that the lack of DPR sensitivity contributes a low bias of approximately 7% to the total bias, these are respectable results.

Zonal mean precipitation rates agree well with zonal mean precipitation rates from the Global Precipitation Climatology Project (GPCP V3.2) product within the 40°S to 40°N latitude band over ocean backgrounds. Estimated zonal means at higher latitudes are underestimated relative to GPCP, due in part to the limited sensitivity of the DPR radar to light snow and drizzle. Over the October 2018 – December 2019 period, in the 40°S and 40°N latitude band, CORRA Ku+Ka+GMI L2 estimates over ocean are low-biased by 4% relative to GPCP, while Ku+GMI estimates over ocean are low-biased by 1%. For the same time period and latitude band, Ku+Ka+GMI and Ku+GMI CORRA L2 estimates over land are currently low biased by 13% and 9%, respectively, with the greatest biases occurring in warm, moist tropical and subtropical regimes.

Note that relative to V06, V07 CORRA Ku+Ka+GMI estimates in the 40°S and 40°N band have decreased by 2% over ocean, while Ku+GMI estimates have increased by 7%. Over land in the same latitudinal band, both Ku+Ka+GMI and Ku+GMI estimates have increased by 9% relative to V06. These changes are effected by nudging initial guess drop-size parameters closer to values established from climatological relationships, which leads to greater proportions of smaller drops and higher rain rates at the lighter end of the estimated rain spectrum, particularly over land regions, where radar-derived, path-integrated attenuations and microwave brightness temperatures do not supply additional drop-size information with great certainty. The changes are justified by the greater fidelity of mean CORRA estimates with raingauge-calibrated ground radar estimates over the continental US, better agreement of CORRA with GPCP V3.2 overall, and greater consistency of drop-size distribution parameter relationships relative to climatology.

The TRMM CORRA V07 algorithm precipitation rate estimates compare well with the GPM CORRA V07. Based upon a limited sample of crossover data derived from the April – September, 2014 GPM-TRMM overlap period, there is an overall high bias of TRMM estimates relative to GPM of approximately 6% based upon matched GPM and TRMM footprints, with a correlation of 0.73 between GPM and TRMM.

Mitigation of the low biases in CORRA L2 estimates, particularly over land, is a priority of the algorithm developers and is an active area of PMM research. A radiometer-only precipitation estimation method designed to quantify precipitation rates below DPR detection limits is currently under development and will be introduced in V08 production. In addition, an experimental product for statistically estimating precipitation at the Earth's surface within the DPR ground clutter (estimated surface precipitation rate), based on retrieved values of precipitation above the clutter (near-surface precipitation rate), have been produced and output in CORRA V07. Although preliminary, these estimated surface rates are substantially increased relative to near-surface rates, particularly in ocean regions where climatologically, precipitation tends to increase from levels above the clutter toward the surface. *It should be emphasized that the estimated surface rates are currently experimental, and more work will be required to stabilize and refine these quantities.*

Users are therefore recommended to still use near-surface precipitation estimates until a more rigorous and meteorologically specific clutter correction method is implemented.

There could potentially be significant changes in the CORRA L2 rain rate products in the transition from GPM V07 to V08 due to modifications and improvements of the CORRA algorithm. Since the GPM and TRMM algorithms share the same software "core", future changes in CORRA should apply to both GPM and TRMM. Again, users of the GPM/TRMM V07 public release products should keep in contact with the Combined Algorithm Team for information regarding these changes.

GPM/TRMM CORRA L2 V06 to V07 Changes

Several modifications have been made to the GPM CORRA L2 algorithm in the transition from V06 to V07. These changes can be categorized as changes in algorithm function and changes in output parameters and format. Regarding algorithm function, the basic algorithm mechanics (i.e., estimation methodology) has not changed, and the same mechanics are applied to both the GPM and TRMM data. The GPM estimation method filters ensembles of DPR Ku reflectivity-consistent precipitation profiles using the DPR Ka reflectivities, path integrated attenuations and attenuated surface radar cross-sections at Ku and Ka bands, and GMI brightness temperatures. The filtered profile ensembles are consistent with all of the observations and their uncertainties, and the mean of the filtered ensemble gives the best estimate of the precipitation profile. The TRMM CORRA algorithm filters PR Ku reflectivity-based precipitation profile estimates using path integrated attenuations and attenuated surface radar cross-sections at Ku band, as well as TMI brightness temperatures.

Probably the most impactful change in CORRA V07 concerns the way in which the precipitation drop-size distribution *a priori* assumptions are applied. In both V06 and V07, the precipitation drop-size distribution is assumed to follow a normalized gamma distribution, and the intercept, N_w, and mass-weighted mean diameter, D_m, are adjusted in CORRA during the estimation process. Initial guess values of N_w are drawn from a lognormal distribution and combined with the Ku reflectivity data to derive a D_m profile using a modified Hitschfeld-Bordan procedure. The D_m values are then used to make a second estimate of the N_w, using an empirical $\log N_w - D_m$ curve. Empirical $\log N_w - D_m$ relationships were previously established by Dolan et al. (2018), Bringi et al. (2021) and others, using disdrometer and microphysics probe observations at various locations over the globe. The initial N_w are nudged toward the empirical N_w, and the nudged values are used to again estimate a revised, initial D_m profile using Hitschfeld-Bordan. This two-step initial guess procedure moves initial N_w values higher for lower D_m (lighter precipitation) and lower for higher D_m (heavier precipitation).

In CORRA V06, the procedure just described was only applied to stratiform precipitation, and there were somewhat different drop-size distribution treatments for ocean and land regions. In CORRA V07, there is (a) no distinction between ocean and land in the initial drop-size distribution adjustment, (b) the empirical curve relating $\log N_w$ and D_m for convective precipitation is shifted to slightly higher $\log N_w$ values relative to stratiform, and (c) the nudging of the initial guess N_w toward the empirical values is done more strongly. The upshot of these changes is that the proportion of smaller drops in the initial guess generally increases for smaller D_m, and this leads to increases in precipitation rates at the lighter end of the precipitation spectrum. For heavier precipitation, drop-size distribution adjustments tend to be more controlled by path integrated attenuations and brightness temperatures, if they are reliable. Overall, however, substantial increases in estimated total precipitation are realized in the mean, especially over land regions. Biases of CORRA V07 relative to ground validation radar and GPCP over land are reduced, and disparities of Ku+Ka+GMI estimates and Ku+GMI estimates over ocean are lessened. In addition, the ocean vs. land contrast of estimated drop-size distributions is less, and the relationships of estimated logN_w and D_m are closer to empirical relationships.

Introduced in CORRA V07 is a clutter or "blind zone" correction of near-surface (above clutter) estimates to create experimental, estimated surface precipitation rates. The clutter zone of the DPR is roughly 0.7 km at nadir view, rising to over 2 km at the swath edges. Climatological relationships between the near-surface estimates and "surface" estimates (actually, at about 0.8 km above the Earth's surface), were established using nadir-view CORRA V07 precipitation rate profile estimates for ocean/land and convective/stratiform classes. This work follows similar studies by Hirose and Nakamura (2004), Liu and Zipser (2013), and Hirose et al. (2021), but uses CORRA V07 profiles to establish the vertical structure climatologies. The climatological relationships are used to scale the near-surface precipitation rates to statistically estimate surface precipitation rates when the surface level is within the clutter. Over ocean, where cloud updraft speeds are relatively weak, climatological mean precipitation rate profiles tend to increase from radar bins just above the clutter toward the surface, and so estimated surface precipitation rates are significantly increased over ocean (8%) relative to near-surface values. Over land, climatological profiles tend to show less variation with height, and smaller increases in estimated surface rates are realized (3%). *Since the climatological precipitation profiles were established based on a limited number of CORRA-retrieved profiles, this clutter correction is deemed experimental in V07, and users are recommended to still use near-surface precipitation estimates until a more rigorous and meteorologically specific clutter correction method is implemented.*

New output variable names and formats have also been introduced in CORRA V07. In particular, the structure name for the Ku+Ka+GMI estimates are called KuKaGMI, and likewise the structure name for the Ku+GMI estimates is now KuGMI. These replace the NS and MS mode structure names of V06, respectively. Similarly, the structure name for the Ku+TMI estimates is now KuTMI. Also, a new structure called OptEst has been included to hold variables derived from an optimal estimation method that fits non-precipitating variables like temperature, humidity, cloud liquid water, and surface emissivity parameters to the radiometer data. These output variables are currently just placeholders, but they will be used in the future to establish background conditions for radiometer-only estimates of precipitation in regions where radar reflectivities are below the minimum detectable of the DPR. Finally, selected variables that were previously estimated at only specified nodal bins of the radar profiles are now defined at full vertical resolution. These include the N_w and D_m profiles, their initial guesses, as well as the profiles of total hydrometeor water contents and fluxes and the liquid portions of those water contents and fluxes. These changes will make it easier to extract and interpret the profiles from CORRA V07.

References:

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